CHAPTER 131

A Bottom Boundary Layer Sediment Response to Wave Groups

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Abstract

A field experiment measured *in situ* sediment resuspension in the bottom boundary layer. Spatially and temporally dense suspended sediment concentration profiles, three-dimensional velocities and pressures were obtained from a location with a flat, fine-sand bottom in Lake Erie in 1992. By use of a conceptual model, ten minute averaged near bottom sediment concentration is found to be proportional to significant wave orbital velocity and group wave parameters. The result attempts to clarify the ambiguity of using a monochromatic wave parameterization for bottom boundary layer model comparisons with measured data containing spectral wave conditions.

Introduction

Sediment transport models encompass many complex physical processes. Shear stresses exerted on the bottom, wave and current interactions and sediment concentration induced stratification are a few examples. Many bottom boundary layer models now have components which attempt to describe these processes. For certain flow regimes these models may accomplish the tasks of modeling natural phenomena.

Recently Bedford and Lee (1994) pointed out that

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an external parameter in the Glenn and Grant (1987) model, the averaged wave orbital velocity, U_b, is one of the most sensitive input parameters required for calculating suspended sediment concentration profiles for a particular coastal bottom boundary layer in Mobile Bay, Gulf of Mexico. A monochromatic wave is used in this bottom boundary layer model for representing wave conditions. With reference to the spectral behavior of real waves, there has been a vigorous debate between researchers concerning the representative wave to be used for such sediment transport modeling. Obviously, a monochromatic wave formulation in the models makes it impossible to directly account for the randomness and nonlinearity of real waves.

It is believed that the nonsteady wave height variation in the surf zone generates the cross-shore component of radiation shear stress; any remnant wave height then contributes to group wave generation (Longuet-Higgins and Stewart, 1964). Grouping effects on near bottom sediment concentration were investigated by Hanes (1987), where he showed that longer period group waves (50 to 100 s) were more effective than shorter period group waves for enhancing sediment concentration. Sato (1992) performed laboratory experiments using bichromatic wave groups and showed enhanced suspended sediment concentrations due to an equivalent amount of monochromatic wave energy. But the question still remains as to how the wave grouping affects the amount of suspended sediment concentration, especially in the very near bottom.

In this paper, the authors will address the above question using a conceptual model of sediment entrainment by wave groups. First, a field experiment and data will be discussed. Then two methods of wave group analysis will follow, the run length method (Goda, 1985) and the envelope function method (List, 1991). Third, a conceptual model will be developed. Finally, group wave effects on the near bottom sediment concentration will be examined by the model and the validity of the monochromatic wave formulation will be tested.

Field Experiment and Data

Fully automated sediment resuspension measurements were made near the southernmost part of Lake Erie from Oct. 20 to Oct. 28, 1992 (Figure 1). A galvanized steel tripod eouipped with instruments and batteries (ARMS, the Acoustic Resuspension Measurement System) was situated on the flat fine sandy bottom in a water depth of 4.5m, 500m offshore. During the deployment, both

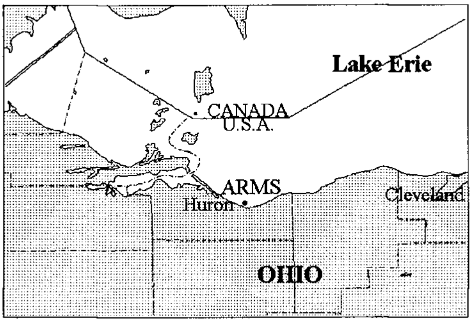

Figure 1. Map of *in situ* experiment site, Lake Erie, United States.

mild and weak storm events occurred and two 50 Mbytes data sets were collected. The suspended sediment concentration profiles are composed of 114 data points comprising a height of 132 cm above bottom (AB). Three-dimensional water particle velocities at the four heights (20, 50, 80, 110 cm AB) and the water pressure fluctuation at 212 cm AB were also obtained. The effective sampling rate of the acoustic concentration profiler was 1 Hz, the BASS (Benthic Acoustic Stress Sensor) current meters was 4 Hz and that of the pressure transducer was 4 Hz.

The flow characteristics of the two storms were extracted from the measured water surface fluctuations and velocity data. The first storm was mild, having a ten-minute averaged significant wave height of 56 cm. The second storm was very weak and not used in this analysis. The duration of the first storm spans almost 10 hours and is the data set analyzed in this paper. Figure 2 shows the significant wave orbital velocity, U_{bs}, calculated directly from the time trace of the orbital velocity, $u_b(t)$, at 20 cm AB, and the accompanying suspended sediment concentration at 5.2 cm AB.

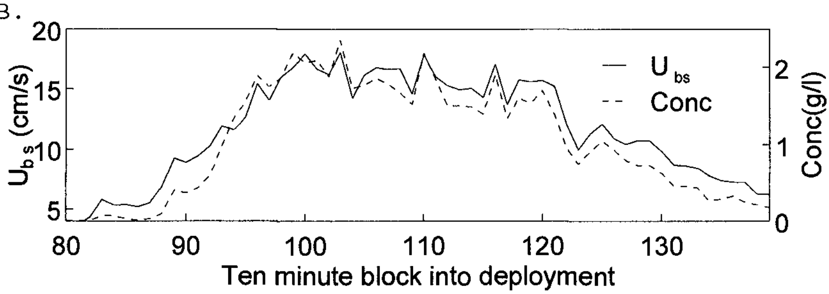

Figure 2. U_{bs} and suspended sediment concentration at 5.2 cm AB.

For subsequent wave group analysis, the wave orbital velocity time series, $u_b(t)$ was examined as opposed to the conventional choice of the surface water fluctuation time series. This is similar to the choice of Hanes(1991) who used $u_b^2(t)$ to do spectral wave group analysis.

Wave Group Analysis and Correlation

Real waves exhibit two distinct spectral energy distributions. One comes from the incident waves, the other comes from group waves. The former can be represented by a statistical or spectral wave estimate. The latter may be characterized by group wave parameters. As the incident wave parameters, the U_{bs}, at 20 cm, is selected for analysis because the U_{bs} shows a higher correlation with the near bottom sediment concentration than does the significant wave height does. In Figure 2 the value of the correlation coefficient between U_{bs} and sediment concentration at 5.2 cm AB is 0.96 and that using significant wave height data is 0.95.

Wave Group Parameterization

Two approaches are taken in the study of wave groups. Mase(1987) emphasized the necessity of more than two group wave parameters to characterize wave groups. One is the statistical investigation of *run length* and the other is the *envelope function*. The former is a measure of height exceedance duration and the latter is a measure of overall amplitude variability. In this paper the run length method by Goda (1985) and the envelope function method of List (1991) are used to parameterize the wave groups.

Run Length Method

Wave groups can be quantitatively described by counting the number of consecutive waves exceeding a threshold value (Goda, 1985). A succession of such high waves is called a run of high waves, and the number of waves is termed the run length, denoted by j_1. Another statistic is the measure of separation between the two consecutive groups denoted by j_2. Figure 3 depicts statistics j_1 and j_2. The crest and trough velocity difference, v_i, and wave order number are defined similar to Goda (1985).

Envelope Function Method

The envelope function method (List, 1991) is a

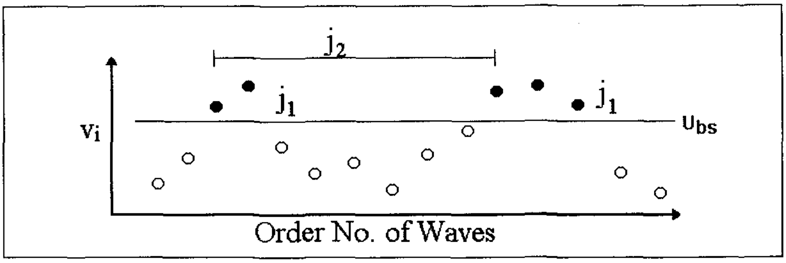

Figure 3. Schematic plot of the run lengths, j_1 and, j_2

method of obtaining the incident wave envelope, A(t) from the incident wave signal (Figure 4). The first procedure for determining A(t) is to high-pass filter the incident wave signal which removes the low-frequency or infra-gravity band waves. Then low-pass filtering of the envelope-related variance signal of A(t) gives the amplitude modulation of the incident waves. In this step the proper selection of a cutoff frequency for removing the incident waves is critical for obtaining a true envelope series. The final step is to multiply the envelope series by $\pi/2$. Using this final envelope function, the GF (Groupiness Factor) is defined as, $GF=1.41S/\bar{A}$ where S is the standard deviation of A(t) and $\bar{A}$ is the mean of A(t).

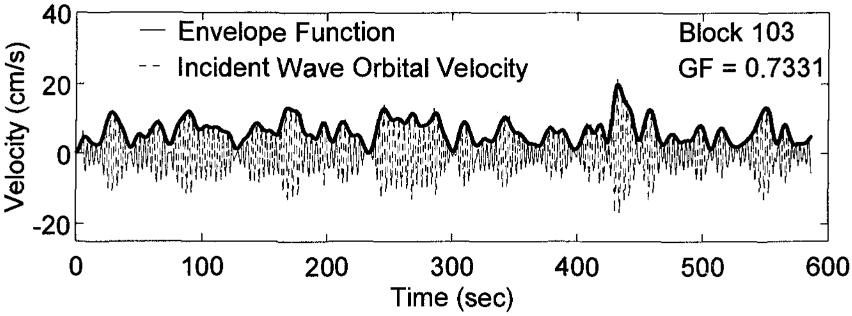

Figure 4. Wave envelope function, A(t)

A Conceptual Model

Implication of Run Length (j_1 and j_2) Value

Figure 5 conceptually examines the near bottom sediment response to four different combinations of run length, j_1, and j_2. In this model only three dominant processes are considered: The entrainment rate as parameterized by v_i, delayed settling by the group waves and sediment settling itself. From the simulations, the high j_1 and low j_2 combination of the upper left box in Figure 5 shows the most enhanced concentration of near bottom sediments. The high value of j_1 enables sediment entrainment and the low value of j_2 allows for the sediment already in suspension to remain there. However, a theoretical analysis by Ewing (1973) reveals that this type of flow field does not occur frequently.

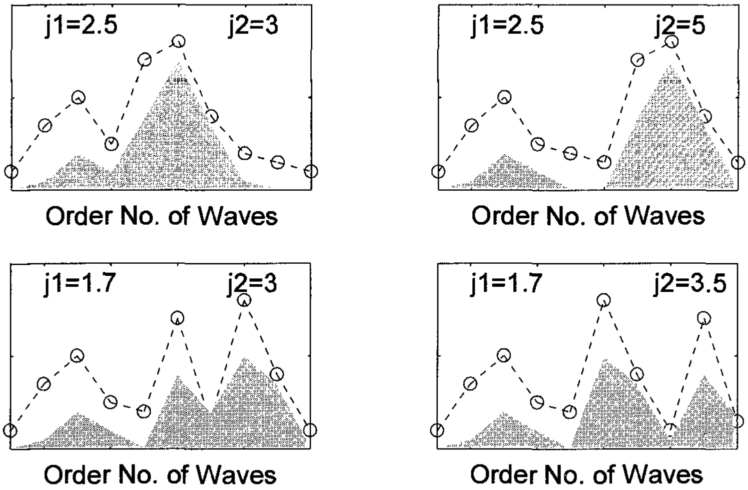

Figure 5. Sediment response due to the change of run length(-o-, v_i ; <u>shadowed</u>, sediment response)

Implication of GF

The groupiness factor defines the shape of the envelope function. High GF values indicate that the group wave envelope function possesses high temporal fluctuations. This high value of GF means a high value of the standard deviation when compared with the mean value of the envelope function A(t) (List, 1991). However, a high GF doesn't necessarily imply high sediment concentration because the probability of clustered high waves in time becomes rare. Figure 6 depicts this concept.

Results

The complete life cycle (10 hours) of a mild storm event in Lake Erie was measured. Consequently the

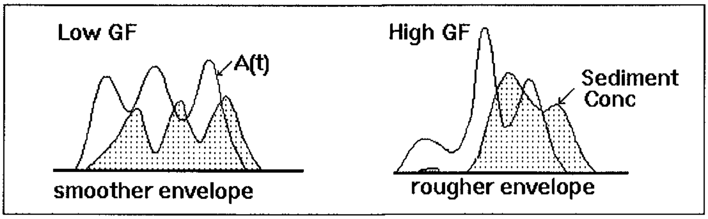

Figure 6. Sediment response due to the change of groupiness factor

evolution of wave groups and the resulting sediment response was completely recorded and analyzed. Run lengths j_1 and j_2 were estimated in 60, ten-minute blocks counted from the time of deployment. Figure 7 shows the changes in run length and the near bottom concentration at 5.2 cm AB.

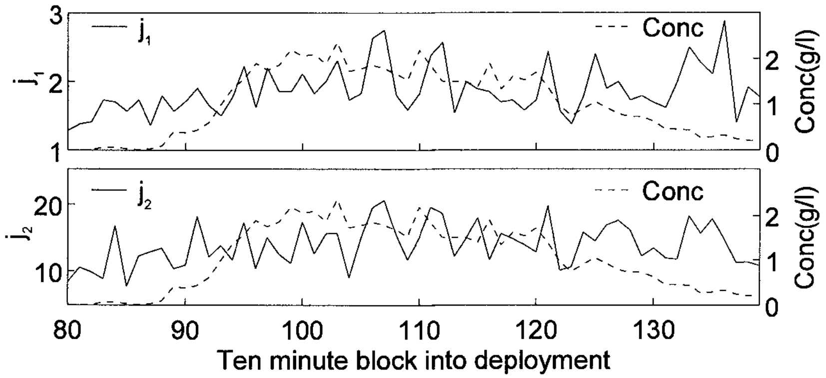

Figure 7. Run lengths, j_1 and j_2 compared with suspended sediment concentraion at 5.2 cm AB

In the figure, the run lengths j_1 and j_2 weakly follow the storm pattern, i.e. spin up and spin down, over the storm period. The correlation coefficients between concentration at 5.2 cm AB and j_1 and j_2 are $r_{j1} = 0.32$ and $r_{j2} = 0.33$, respectively. j_1 and j_2 show fluctuations even during the middle or equilibrium period of the storm.

Figure 8 shows the GF variation during the storm period and near bottom concentration at 5.2 cm AB. Although it loosely follows the storm pattern, it is hard to extract any significant correlation (r_{GF}=0.36) between the GF and the near bottom concentration at 5.2 cm AB.

As indicated by the conceptual model group waves

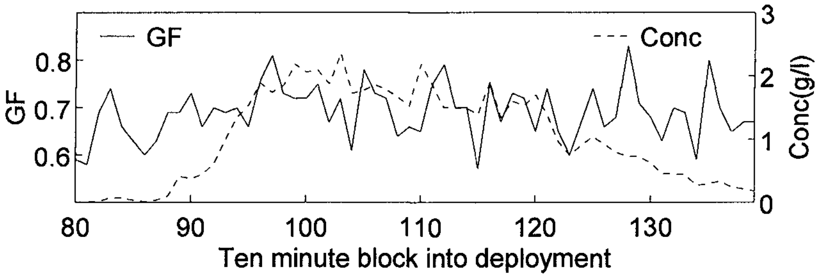

Figure 8. Groupiness factor(GF) compared with suspended sediment concentration at 5.2 cm AB

enhance the suspended sediment concentration by continuing entrainment of settling sediments which are already in suspension. To further see the effects of group waves we have to pick blocks with the same wave energy levels and compare only the suspended sediment concentration by group waves. In 10 hours of resuspension processes there are 5 pairs of comparable 10 minute blocks: 102 and 103; 107 and 108; 114 and 115; 119 and 120; and blocks 136 and 137. These pairs have very similar wave kinetic energy. Figure 9 summarizes the results.

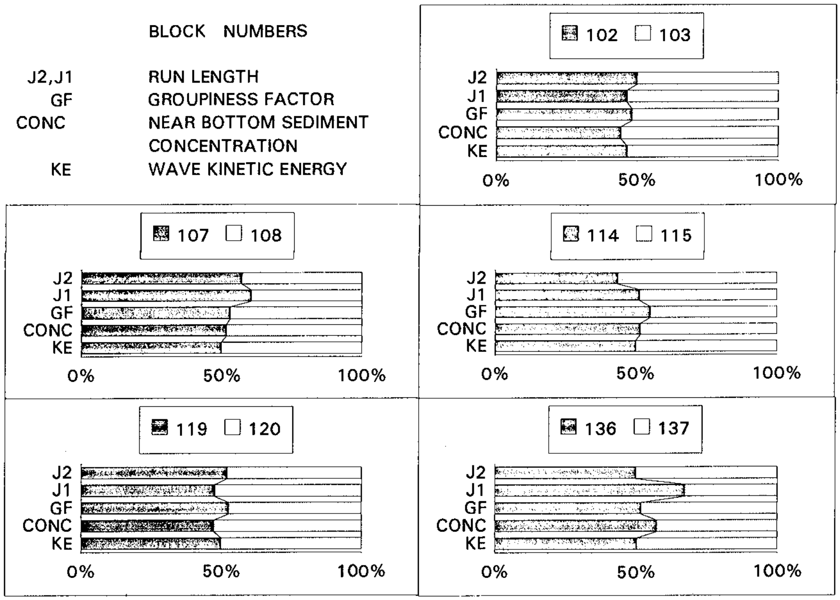

Figure 9. Test results of the conceptual model

From the first row of the upper right box, the combination of j_1(B102, darker shadow bar)<j_1(B103), j_2(B102)=j_2(B103) , GF(B102)>GF(B103). Thus the concentration of B102 is lower than that of B103. This case was also characterized by the conceptual model having lower concentration. In the second comparison, the group wave parameters of block 107 are bigger than those of block 108. Among them, j_1 of block 107 shows the biggest difference. The result is higher concentration in block 107. It is noted that, even though the j_2 of block 107 is bigger, the concentration of block 107 is higher. In other words, we can see the dominance of j_1 in determining the amount of concentration. This idea is also suggested by the conceptual model. The third case examines how j_2 can contribute to the enhancement of concentration. j_2 of block 114 is far smaller than that of block 115, and results in a higher concentration. The fourth comparison in the bottom row, shows once again the dominance of j_1 compared to GF. j_1 of block 119 is smaller and results in a lower concentration. Also, a bigger j_2 in block 110 helps to enhance the concentration. In the final comparison, j_1 of block 136 is overwhelming. It leads to a much higher concentration. Again it shows the dominance of j_1 in being the most effective group wave parameter in denoting enhanced concentration.

Conclusions and Discussions

From the *in situ* measured data set we can verify the concepts of an enhanced near bottom suspended sediment concentration by group waves. Using the results obtained in this paper we can clarify some of the arguments in the study of sediment entrainment and resuspension due to both incident waves and group waves.

i) Incident waves are the dominant forcing in determining the suspended sediment concentration at 5.2 cm AB.
ii) Group waves may induce still higher concentration by delaying the suspended sediment settling.
iii) The value of j_1 governs the amount of enhanced sediment concentration and is the obvious indicator of group wave effects on the near bottom suspended sediment concentration.
iv) The run lengths, j_1 and j_2, are sufficient group wave parameters for describing enhanced sediment concentration. The GF(groupiness factor) is redundant.
v) The monochromatic wave assumption in the bottom boundary layer models is correct to 96 percent

correlation coefficient when the significant wave orbital wave velocity is substituted for the monochromatic wave in a ten minute averaging period.

vi) The remaining accuracy will be accounted for by group wave parameters particularly j_1.

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